A STUDY ON
WIND ENERGY CONVERSION SYSTEMS (WECS), COST EVALUATION, AND PROSPECTS FOR COST REDUCTION

FINAL REPORT

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A STUDY ON WIND ENERGY CONVERSION SYSTEMS (WECS), COST EVALUATION, AND PROSPECTS FOR COST REDUCTION

FINAL REPORT

1 SUMMARY

To determine the present cost to manufacture and install wind energy conversion systems and to identify opportunities for potential reduction in these costs a survey of major European and North American manufacturers was made to obtain WECS component cost data and other information relative to their production cost. Thirty manufactures surveyed nine HAWT and two VAWT manufacturers volunteered data and information. The quantity and quality of data was less than expected and has limited the accuracy and scope of the study. The results of the study do however indicate that significant progress in cost reduction is being made and that there is further opportunity.

A 60% reduction in installed costs has been realized during the last five years and industry estimates a further 17% reduction in the next year. Industry is being encouraged to reduce costs as U.S. incentives on wind farm development are removed. The study indicates that emphasis in design should be placed on lighter weight structures and maximum use of commercially available components. It appears the lowest cost HAWT design will use integral speed increaser/chassis assemblies and truss or lattice type towers. There is also indication from manufacturers that improved airfoils for higher aerodynamic efficiency are being considered.

The study indicates that VAWT design must move to lighter weight structures and commercially available drive train components. Higher efficiency rotors, possibly using composite blade construction, is also being investigated.

Indications were obtained that WECS ratings for minimum annual levelized cost of energy will settle out between 300 kW and 1000 kW.

2 INTRODUCTION

2.1 BACKGROUND

Energy from the wind although free and non-polluting in its natural form has enjoyed low levels of acceptance as a source of practical electrical energy because of the high cost and uncertain reliability of the conversion systems necessary and because of their inability to deliver firm power without the addition of very expensive storage systems. Wind energy conversion systems (WECS), although the subject of concerted research, design and development projects by industrial nations since the threat of oil shortages and price increases of the last decade, have not yet reached combined levels of effective cost and reliability to interest utilities and consumers in their purchase as economic and practical sources of electricity. In general the cost of electricity as computed by utilities from WECS is still considerably higher than that produced by hydro, coal, heavy oil and nuclear plants. A few exceptions may exist in remote communities where electricity supplies are dependent on diesel power plants. Even in these places however, the high cost of transportation and installation may exceed fuel savings. Also many remote communities are in developing countries and do not have the resources for investment in alternatives having high capital costs. Reductions in demand and price for oil on the world market have also slackened interest in renewables in general.

Evidence of improvements in equipment reliability has been obtained from operational experience with the many multi-unit WECS installations on wind farms in California. Capacity factors for early machines were only of the order of 13 percent however more recent designs and equipment have shown capacity factors of up to 30 percent which is a more attractive and acceptable situation. The low capacity factor of early machines is a result of over rating the machines by installing generators whose maximum output could only be reached in very high winds. It must be considered, however, that these improvements in reliability and performance are evidenced by only a few years experience. Confirmation of reliability and performance parameters will not be known for at least fifteen or more years.

The average cost of an installed WECS has been reduced by almost 60 percent in the last five years from about C$4,200/kW to about $1,700/kW. Industry estimates are that a further 17 percent reduction on the latter may be expected in 1986.

The importance of cost reduction is becoming increasingly important to existing manufacturers as business conditions in the dominating California wind farm market continue to evolve. Tax benefits and grants available to WECS purchasers and investors are diminishing under pressure from tax reform advocates. Also prices paid by the utilities for electricity are down from levels paid in the early eighties because of depressed oil prices although prices are expected to rise again because of rising levels of demand resulting from continued economic growth and expansion in the Southwest. Where WECS equipment was once purchased sight-unseen by individuals wishing to defer income tax through investment tax credits, the equipment must now sell more on the basis of its long-term investment value which is dependent upon initial costs, operational and maintenance costs, performance, and reliability. This situation is encouraging the WECS industry to design and develop more cost effective equipment.

Industry have been concentrating on improvements in technology and increases in size of WECS to achieve effective cost reductions while continuing to maintain or improve capacity factors and reliability.

In the area of technology development, there are many opportunities that arise because of a better understanding of operational, structural, and dynamic loads; more experience with materials and fabrication techniques; improvements in aerodynamic efficiency of blades; simpler and more compact control devices; and reduced operating and maintenance requirements. The opportunities for cost reduction in each of these areas, although significant in combination, are each more marginal on their own.

In the area of economy of scale, designers are concerned with factors of individual machine size and potential volume of manufacture. There is, of course, some direct relationship between these factors because the ultimate market is for kW capacity and kWhr/yr somewhat irrespective of the size or quantity of machines.

Canadian industry has not yet reached the introductory stages of penetration into the world WECS market. Although government support for research and development of the vertical-axis Darrieus machine has been effective in developing a competitive technology, there has not been sufficient government, private and utility incentive to create a productive industry as has occurred in the U.S., Denmark, Holland, Belgium and more recently in the U.K. The fact that in Canada a general shortage of electrical energy supply does not exist and no commercial incentives are available has not encouraged industry. It is being increasingly recognized however, that there are a considerable number of locations where the supply of electricity is dependent upon diesel generators and where because of high average annual wind speeds, WECS may have good application. Also because of community growth and consolidation of population around places where electricity and other community services are available, the demand for electricity in many remote communities is increasing rapidly both in Canada and elsewhere.

Recognizing that WECS offer potentially the most economic alternative for electrical supply in some areas and wishing to obtain an estimate of the future cost of WECS, Energy, Mines and Resources Canada, Solar Energy Development Program has funded a study to investigate current technology and identify potential cost reduction opportunities in the manufacture of WECS.

The report that follows describes the results of the study and makes recommendations for directions to take toward more cost effective design.

2.2 PURPOSE

The purpose of this study is to identify and quantify for Energy, Mines, and Resources, Solar Energy Development Program and for WECS industry researchers and planners the distribution of costs among the elements of a WECS, and the opportunities to reduce these costs by appropriate choices of design configuration, technology, component parts, and materials. Size and its interdependence with volume and market opportunity is also a major consideration. Operational, warranty, and maintenance costs are also an important element in the

total cost equation which must be addressed. The parameter selected for evaluation of costs was chosen to be annual levelized cost of energy, $C/kWhr/yr.

2.3 METHODOLOGY

The study was conducted and guided by the tasks described in the study statement of work. They are listed below:

1. Survey of available literature and previous experience with WECS cost reduction analysis.
2. Identification of sources of information.
3. Development of a survey strategy and collection technique.
4. Analysis of data received.
5. Calculation of results.
6. Preparation of report.

Central to the study strategy was an effort to involve as many manufacturers and other industry participants as possible and also to guarantee to those who provided data and information that any proprietary information provided, of which disclosure might be harmful to the supplier, would not be divulged.

A questionnaire was designed by the study team in consultation with production and design engineers from three manufacturers in Canada. From them, we obtained advice relative to the appropriateness of questions in the questionnaire and an impression of how extensive our queries regarding costs could be before we intruded too deeply into sensitive areas.

Each manufacturer was also offered a certificate of non-disclosure that instructed them to identify information they considered proprietary and that they wished camouflaged to the extent that it could not be identified with their products. Each supplier of information was also offered that an advance copy of material related to their contribution be provided to them for their approval prior to publication. Questionnaires for both horizontal and vertical-axis machines were developed. Appendix A contains a sample copy of each.

Questionnaires were sent to thirty manufacturers in Europe, the United Kingdom, the United States, and Canada. Manufacturers were

selected as much as possible from those giving evidence of application of comprehensive design and engineering methods and practice and having experience in the production and installation of units in large volume. Several manufacturers in Canada, Denmark, Holland, and Germany were visited to gain an impression of the techniques used to design and manufacture WECS equipment and to solicit their participation.

Returned questionnaires were studied and cost and production data extracted and manipulated to reduce it to manageable form for comparison with data from other respondents. Cost data for components, assemblies, and complete units was reduced by normalization with respect to weight, rated output, and annual energy production. Where data was not available or difficult to interpret, the respondent was contacted by telephone to discuss and clear up uncertainties.

Component manufacturers and suppliers were also surveyed to obtain information on price and volume effects and to learn what special or additional design and engineering must be incorporated into their equipment when used in the manufacture of WECS. Components of most interest were rotor blades, gearboxes, and generators.

2.4 RESPONSES

There were eleven responses to the questionnaire. Two were from VAWT manufacturers and nine were from HAWT manufacturers. Unfortunately, the response was not as high as had been wished. Frequent follow up efforts to solicit participation of non-respondents were largely unsuccessful. One HAWT manufacturer provided three responses, one for each of three machines of similar design but different ratings.

Manufacturers contacted who did not respond stated reasons such as time constraints due to business pressures, unwillingness to divulge proprietary information, and non-appreciation of study value.

Table 1 lists respondents to the study questionnaire and a summary of production experience.

TABLE 1: RESPONDENTS TO QUESTIONNAIRE

Manufacturer	Type	Number of units produced
Adecon Energy Systems Inc.	VAWT	2 (Prototype)
Bergey Windpower Co., Inc.	HAWT	275
Danwin A/S	HAWT	23
Howden Group Canada Limited	HAWT	75
Indal Technologies Inc.	VAWT	2
MAN Neue Technologie	HAWT	370
Vestas A/S	HAWT	2,000
Wincon Energy Systems A/S	HAWT	1,300
Windtech Incorporated	HAWT	91

3 THE WIND ENERGY CONVERSION SYSTEM (WECS)

3.1 GENERALIZED MACHINES

To provide a standard framework against which to compare data reported by the respondents and to enable design of an appropriate questionnaire, WECS were segregated into their basic component parts. Because of the substantial differences between vertical-axis and horizontal-axis wind technology, the two designs were considered seperately throughout much of the study.

The VAWT equipment was segregated into the basic elements illustrated in Figure 1. The HAWT equipment was likewise segregated into the basic elements illustrated in Figure 2. Although there were sufficient subtle differences between individual machines in each category to cause some difficulty in making easy comparison of component or element costs, the generalized machines served as a useful tool for the analysis and comparison work.

3.2 VERTICAL-AXIS MACHINES

The two vertical-axis machine manufacturers who responded to the questionnaire produce very different machines. The Indal Technologies Inc. 500 kW machine uses three pairs of guy cables to support the rotor. The Adecon Energy Systems 150 kW unit uses a lattice external space

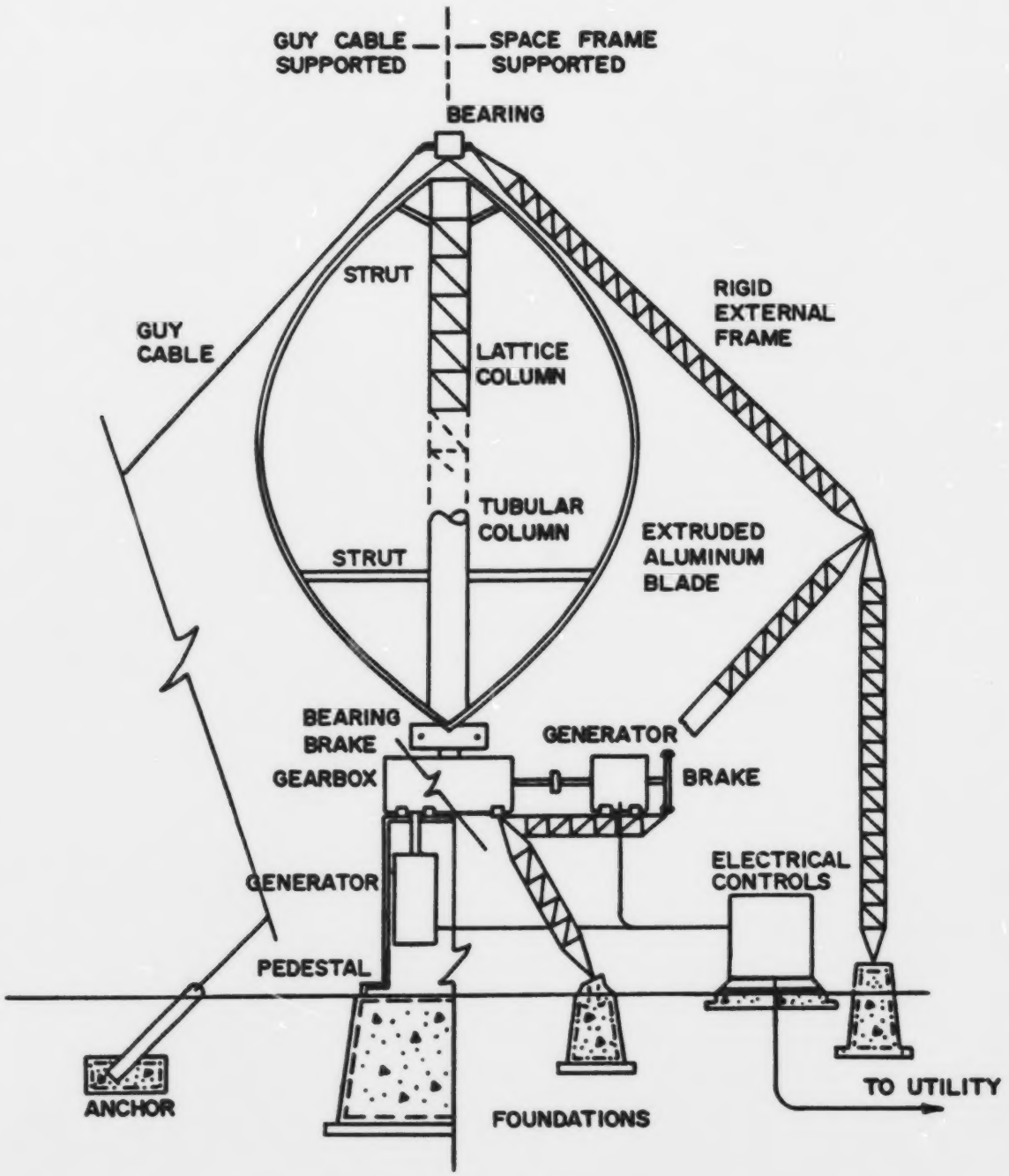

Figure 1. VAWT, Basic Elements for the Study

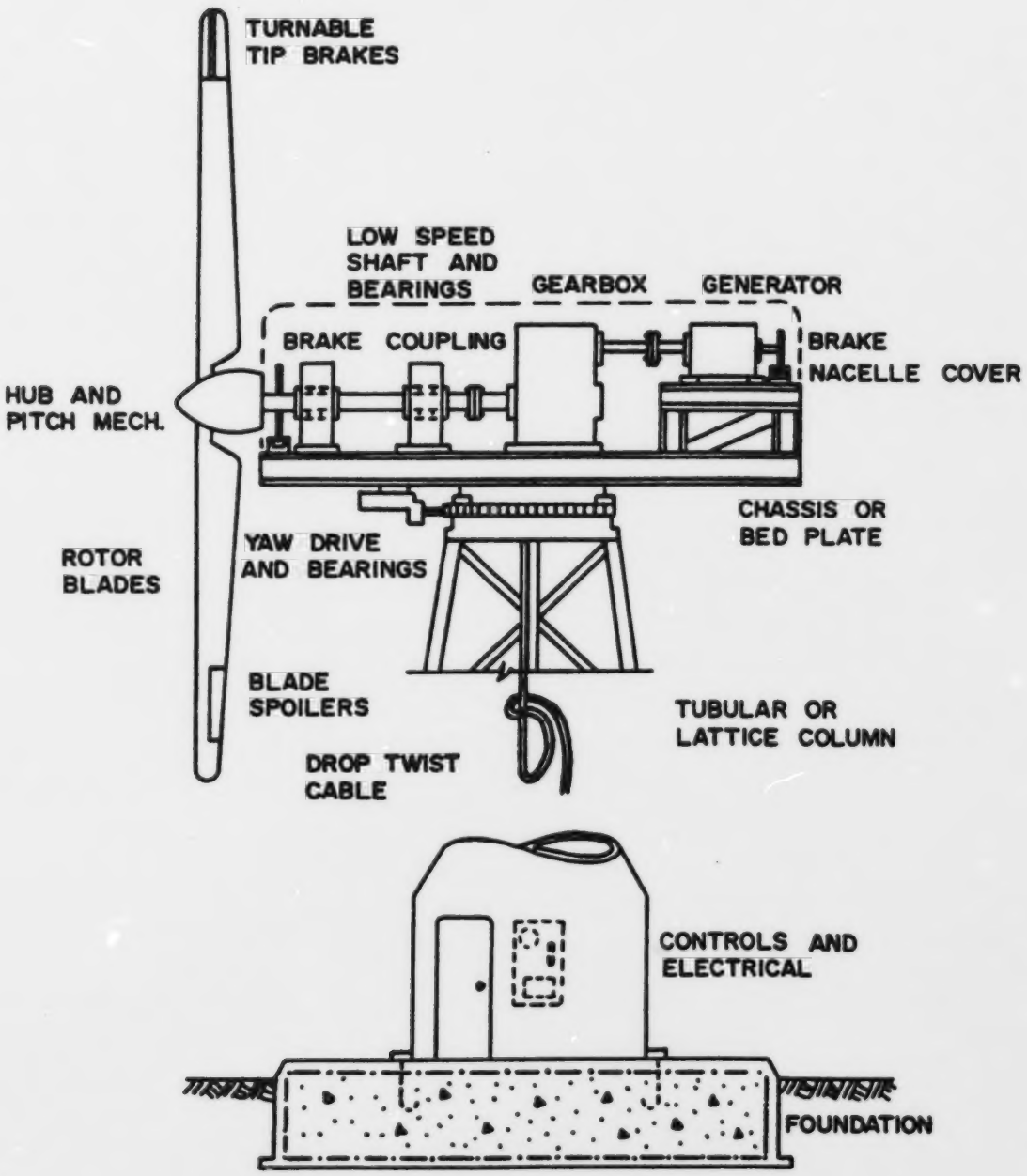

Figure 2. HAWT, Basic Elements for the Study

frame to suspend the rotor off the ground. Unfortunately, with only two responses to the questionnaire, it is impossible to examine detailed costs of these machines without revealing information considered confidential and proprietary by the manufacturers. It is therefore necessary to restrict comments to a description of the machines and general comments regarding performance of the machines related to their selling price. Table 2 sets out the selling prices, estimated performance, and operational characteristics of the machines. It must be pointed out also that for both machines energy performance is estimated and not based on actual records of long term performance.

TABLE 2: VERTICAL-AXIS WIND TURBINE PARAMETERS AND PRICES

	A	B
Rated Output kW	500	150
Rated Wind Speed m/s	17.5	19.5
Swept Area m^2	595	315
*MWh/yr produced @ 6 m/s (est.)	556	265
@ 7 m/s (est.)	877	365
@ 8 m/s (est.)	1,210	450
**Capacity Factor @ 6 m/s	13	20
@ 7 m/s	20	28
@ 8 m/s	27.6	34.2
Weight of Blades (Aluminum) kg	2,860	800
Weight of Struts (Steel) kg	1,452	64
Weight of Rotor Column (Steel) kg	13,720	1,800
***Selling Price $C	570,000	94,400
Selling Price/kW (Rated) $C	1,140	630
Selling Price/MWh/yr. @ 6 m/s $C	1,025	355
/MWh/yr. @ 7 m/s $C	650	260
/MWh/yr. @ 8 m/s $C	470	210

* Projected annual energy for Rayleigh Distribution at 10 m elevation. Vertical Shear coefficient, x = 0.15.

** Capacity Factor = $\frac{\text{kWh/yr @ x m/s X 100}}{\text{Rated Output (kW) X 8760 (hrs/yr)}}$

*** Machine selling price is manufacturers quoted price fob factory less 5 percent which appears to be an industry-wide discount for purchase of more than one machine.

Major modifications to the Indal Technologies 500 kW machine are being considered. The new design would involve use of a rotor with a greater diameter at the equator and tailored airfoils which it is claimed will increase energy yield. Adecon also have new design concepts for rotor support that they wish to explore in the near future. They plan to increase the rotor aspect ratio.

3.3 HORIZONTAL-AXIS MACHINES

Nine HAWT manufacturers questionnaires were returned providing information on machines ranging in size from 10 kW to 190 kW. There were one Canadian, six European, and two U.S. responses. The population of responses was spread reasonably well over the range of WECS and there were a majority of responses in the region of technology typified by the modern Danish commercial wind farm machine. This is the type of machine and technology that has become familiar in large California wind farms and in smaller wind farm projects in Denmark. Many of these manufacturers are also developing projects to install or license manufacture of their machines in India. There is also increasing interest in these machines for application in Canada, particularly in Alberta where net power billing is possible, and in remote northern communities with diesel electric generation.

In general, the Danish commercial wind turbine has a very standardized form using three stall-regulated fibre-reinforced plastic (FRP) blades, a speed increasing gearbox, an induction generator, and an active yaw drive. The machines often vary with respect to design of aerodynamic overspeed brakes on blades, location of rotor brake, mounting of gearbox and generator, use of a two-speed generator or two generators for dual rated machines, tower type, and controls. Early Danish machines were rated in the 40-60 kW range but now, with confidence in performance, are being designed in larger sizes in the range of 200 kW. Success of the Danish machines has been largely influenced by strong support received from the Danish government for fair interconnection and power purchase policies and testing certification and design assistance from the Danish Research Establishment at Risø. A design strategy based on simplicity, practicality, and appropriate scale has also enhanced their success.

Four representative and similar horizontal-axis machines are compared in Table 3 to illustrate the close comparison of cost and performance information received from Danish manufacturers. Also these four provide an interesting comparison because of the slight variations in design, particularly in controls and overspeed protection and the variation in size or rating. These four were selected from the sample because of the high level of information provided compared to other responses. Responses from other manufactures were also not representative of any specific technology form, were more individualistic in design, and were characterized by a wider cost distribution.

TABLE 3: DISTRIBUTION OF HORIZONTAL-AXIS WIND TURBINE RELATIVE COSTS
(Installation not Included)

	A	B	C	D
1. Rotor				
Blades	22.5	21.8	23.6	23.7
Hub	2.5	2.3	3.9	2.3
Subtotal	25.0	24.1	27.5	26.0
2. Drive Train				
Low Speed Shaft	4.0	4.8	3.8	5.5
Speed Increaser	13.8	12.1	10.9	15.1
High Speed Coupling	1.3	0.9	1.0	---
Generator	8.8	6.6	5.7	9.5
Brake	2.0	2.4	2.1	2.1
Subtotal	29.9	26.8	23.5	32.2
3. Structural				
Chassis	1.9	2.2	3.8	3.9
Yaw Mechanism	3.8	4.5	3.5	1.3
Cover	3.1	3.0	3.0	2.4
Tower	17.1	19.4	20.3	10.4
Foundation	7.2	7.2	7.1	9.2
Subtotal	33.1	36.3	37.7	27.2
4. Controls and Switchgear	12.0	12.8	11.3	14.6
TOTAL	100.0	100.0	100.0	100.0

To make this comparison, component selling prices were reduced to percentages of the total selling price of the machine. The table clearly describes the relative cost (assuming selling price reflects cost) of the various components.

An advantage of the more or less similar design of Danish machines is the desirable economy created by the volume demand for components many of which are used by several manufacturers.

The percentages in Table 3 vary only slightly in most cases. Where large variations exist, there is generally a marked difference in technology or material. The important components are:

1. Blades (21.8-23.7 percent)
2. Steel Tower (10.4-20.5 percent). The low cost tower "D" is a steel lattice tower while others are tubular welded construction.
3. Speed Increaser Gearbox (10.9-15.1 percent)
4. Controls and Switchgear (11.3-14.6 percent)
5. Generator (5.7-9.5 percent)
6. Foundation (7.1-9.2 percent)

The remaining components account for 17-21 percent of the cost. If we included foundations, which are site dependent, these account for 25-28 percent. Significantly large cost reductions in any one of the remaining components will produce relatively small changes in the overall cost. This comparison is very straightforward and does not dwell on the cost and performance interrelationships and dependencies. It does however highlight those areas where major effort must be directed if substantial cost reduction of WECS equipment is to be realized. It also intrinsically indicates that significant cost reduction potential can also be realized through a constant effort to minimize the cost of all of the component parts without a net reduction in effective performance.

In Table 4, the overall performance estimates and selling prices of all of the horizontal-axis wind turbines surveyed are shown. The actual ratings have been normalized and other descriptive information not included to prevent positive identity of the data suppliers or their products. It can be noted that with machines (B) through (F) there is a general indication that increased size leads to more economic machines with lower C$/kW output and lower annual levelized cost C$/MWh/yr of

energy production. It must be noted that these costs do not include foundations, installation costs, or the equipment necessary to interface the equipment to an electrical distribution system. These items although significant do not vary greatly from one design to another. In general they will decrease somewhat with increasing WECS size.

TABLE 4: HORIZONTAL-AXIS WIND TURBINES PRODUCTION AND LEVELIZED COST

	A	B	C	D	E	F	G	H
Normalized Output kW	100	55	42	33	30	27	24	12
MWh/yr/kW								
@ 6 m/s	2.04	2.28	2.09	2.46	2.70	1.87	1.5	1.95
@ 7 m/s	2.86	3.03	2.81	3.79	3.55	2.71	1.91	2.57
@ 8 m/s	3.68	3.69	3.51	4.23	4.34	3.54	2.39	3.2
Normalized Capacity Factor	74.2	83.9	77.4	90.3	100	67.7	54.8	71.0
Selling Price/kW $C	1900	890	920	1140	1250	1040	960	1850
Selling Price/MWh/yr $C								
@ 6 m/s	930	390	440	460	460	560	640	960
@ 7 m/s	660	290	330	340	350	390	500	720
@ 8 m/s	510	240	260	270	290	290	400	580

Although there is an observed trend toward economy of scale in the center of the range the largest machine, at almost twice the rating of the next in the range, is only slightly better from an overall performance aspect than the smallest. The machines having highest selling prices/kW also surprisingly have lower capacity factors which of course forces the levelized cost much higher.

4 THE SURVEY

4.1 ROTOR BLADES

4.1.1 Introduction

Windmills and windchargers used for farm water pumping and electricity generation prior to rural electrification commonly had blades made from steel sheet metal or carved from wood. Usually the metal

blades were formed of light guage galvanized sheet and the wooden blades were made from a single length of sitka spruce, a wood commonly used for sailing ships' masts and spars. With little maintenance they offered many years of useful service and could often be repaired or replaced by the owner in his own shop. Since the revival of modern wind turbines in the mid-seventies, welded steel, extruded aluminum, fibre-reinforced plastics (FRP), and wood/epoxy laminates have become more common because of their superior strength and the larger sizes required. Also during the last half century the high level of experience with use of these materials in other applications requiring a high level of quality control to perform properly enhances their application for wind turbine applications.

Blades for the large horizontal-axis 2.5 MW US Mod 2 machines were fabricated from steel. Also the structural component of the blades for the 4 MW vertical-axis machine at Cap Chat, Quebec, are fabricated of steel. A Dutch manufacturer (Polenko) also manufactured steel blades for their range of 60 to 200 kW machines. Steel offers some desirable fatique resistence and strength qualities at some penalty in weight and cost to fabricate. Steel blades must also be carefully finished to resist corrosion and may be difficult to shape and to maintain smoothness when welded.

Extruded aluminum blades are used on all vertical-axis Darrieus machines manufactured in Canada and the USA. To date aluminum has been used successfully only where a constant section blade with predominantly tension loads is applicable. Aluminum is not as resistant to fatigue as steel, wood or FRP and is also affected by corrosion.

FRP blades have been used widely on HAWTS manufactured in the USA and Europe ranging in size from a few kiloWatts to a 4 MW machine manufactured by Hamilton Standard. FRP blades are manufactured by a variety of methods which may be used in combination. The most common are:

1. Hand lay up in molds. This process is much like that used for manufacture of small boats. The components so laid up are then fastened to a structural framework.
2. Filament wound. This process involves winding continuous fibre tape and filaments about a mandrel and simultaneously applying

resin. The mandrel may remain an integral part of the blade or may be a tool that is reused.

3. Pull-truded blades are used in both the 1 kW and 10 kW Bergey wind turbines. This process is very similar to the extrusion process for aluminum blades and is only possible so far for constant section blades.

Wood/epoxy laminated blades are manufactured by Gougeon Bros. of Michigan, USA and Gifford of Great Britain. A few small WECS manufacturers also fabricate their own wood laminated blades. A number of two- and three-bladed rotors have been fabricated for machines ranging from 25 kW to 750 kW.

4.1.2 VAWT Blades

The vertical-axis machines included in this study both use extruded aluminum sections which are later bent lengthwise to form the required curved shape. The Indal machine uses a single extrusion which is bent point by point to form a close approximation to the desired troposkein shape. The Indal blades are not painted. The Adecon blades are fabricated of four single extrusions of much thinner wall thickness. Each extrusion is stretch bent to avoid buckling during bending and then cemented together with an adhesive and painted. A comparison of rotor characteristics for the two machines is shown in Table 2.

Because there were only two respondents who provided information on vertical-axis machines it is necessary to restrict our analysis and comparison to a physical and performance analysis as shown in Table 2. Because cost of extruded aluminum is a function of weight, it is apparent that lighter blades are desirable.

4.1.3 HAWT Blades

4.1.3.1 General Comparisons:

Table 5 provides a comparison of representative machines from the respondents and a number of other European and North American manufacturers.

The table reveals several interesting observations regarding predeliction in design, materials, and functional characteristics of the blade.

TABLE 5: ROTOR CONSTRUCTION, HAWT BLADE MATERIAL, AND ROTOR CONTROL

Manufacturer		Output [kW]	Size/Dia. [m]	Blade Material [#]		Control
Berewoud	(N)	8-150	8-20	FRP	(3)	Blade Pitch Control
Bergey	(US)	1-10	7	FRP	(3)	Passive Blade Twist
Bouma	(N)	100-200	16-20	FRP	(3)	Turning Tip Brakes
Bonus	(D)	22-100	8.7-18.5	FRP (AeroStar)		Turning Tip Brakes
Carter	(US)	25-250	9.8-20.5	FRP	(2)	Passive Pitch Control
Danish Wind	(D)	340	31	FRP	(3)	Blade Pitch Control
Danwin	(D)	99-180	19.6-22.2	FRP	(3)	Blade Spoilers
Enertech	(US)	40	13.4	Wood/Epoxy	(3)	Tip Spoilers
EST	(US)	50,250	165,24.4	Wood/Epoxy	(2)	Tip Spoilers
Howden	(UK)	60	15	Wood/Epoxy	(3)	Blade Tip Brakes
Howden	(UK)	330	31	Wood/Epoxy	(3)	Blade Pitch Control
Lagerway	(N)	20-600	10	FRP	(3)	Passive Pitch Control
MAN	(FG)	40	12.5	FRP	(2)	Blade Pitch Control
MBB	(FG)	25	12.5	FRP	(1)	Blade Pitch Control
Nordtank	(D)	150	20.5	FRP	(3)	Turning Tip Brakes
Northwind	(US)	16	9	Wood Laminate	(2)	Passive Pitch Control
Reymo	(D)	18.5-75	10.7-17	FRP	(3)	Turning Tip Brakes
Riisager	(D)	120	20.4	FRP	(3)	Turning Tip Brakes
Sudwind	(FG)	15	7	FRP	(3)	Hinged Blades
Micon	(D)	110	19.6	FRP	(3)	Turning Tip Brakes
W E Group	(UK)	200/250	25	Wood/Epoxy	(3)	Partial Span Pitch
Windmatic	(D)	95	17	FRP	(3)	Turning Tip Brakes
Vestas	(D)	90	17	FRP	(3)	Turning Tip Brakes
Windtech	(US)	40	17	FRP	(2)	Passive Pitch Control

The following describes some of the general trends regarding design choices by manufacturers.

- o Manufacturers in Denmark and Holland favor machines with three FRP blades. Machines with outputs in the range of 50-250 kW usually have fixed pitch blades and are stall regulated to limit power

output above rated windspeed. The most popular rotor overspeed protection is provided by turnable tips or flaps that deploy due to centrifugal forces. Some tips reset automatically while others must be reset manually.

- o American and British manufacturers appear to favour wood/epoxy blades.
- o British manufacturers appear to favor machines with three wood/epoxy blades with either turning blade tips for overspeed control or fully pitching blades.
- o American manufacturers have more variable designs and offer two- and three-bladed machines and several blade overspeed control techniques.
- o Most U.S. machines are free yaw while most Danish wind farm machines have yaw controls.

4.1.3.2 Fibre-Reinforced Plastic (FRP) Blades:

Two major manufacturers who supply FRP blades to WECS manufacturers are: Alternergy, Danish Commercial Energy A/S of Denmark and its American subsidiary AeroStar; and Ventilatoren Stork of the Netherlands. There are also a few WECS manufacturers who produce their own FRP blades but they are in the minority.

FRP blades are manufactured using several methods. The choice of method seems to depend upon individual preference of the designer and the existence of native skill and know how. There is inadequate data available from respondents to make cost comparisons regarding fabrication methods and also insufficient experience to date to assess reliability and performance characteristics. Most blade manufacturers are secretive with regard to details of technologies used to fabricate blades. Blade manufacturers provide custom design and exclusive rights to the WECS industry.

4.1.3.3 FRP and Wood/Epoxy Blade Costs:

The choice between wood and FRP as the construction material for blades is a difficult one for WECS manufacturers to make. The basic considerations which must be made with regard to cost and reliability are closely interwoven with considerations of rotor and drive train

design, strength, performance, life expectency and maintenance requirements. Figure 3 shows blade cost versus recommended WECS rating from one large FRP blade manufacturer. The graph shows that effective cost/kW rating is very dependent on average windspeed for which the rotor is designed. The linear relationship between cost and rating indicates that WECS rating and blade size do not offer any obvious economy of scale.

Information obtained during discussions with manufacturers regarding larger blades indicated that two things may happen. First, the technology may experience further improvements from the incorporation of newer composite materials such as carbon fibre. Second, as rotors get larger, two blades may be more common than the current three. This will reduce rotor costs directly but possibly at the expense of a more complicated and expensive hub. Finally, the development of better airfoils may improve blade performance and increase energy production.

Information obtained from Gougeon Bros. indicates that the cost of wood/epoxy laminate blades for 60-100 kW machines with blade lengths of 6.4 to 7.8 m will be similar to that of FRP blades. For larger sizes (600-1,000 kW) with blade lengths from 20.0 to 26.4 m, the wood/epoxy blades appear to have some cost advantage. Prices quoted in this range are as much as 30% less than those for FRP blades. They are also considerably lighter and thus may allow for reduction in the weight of structural and drive train components. While Gougeon Bros. expect wood/epoxy blades to remain competitive and to maintain cost advantage over FRP as blade designs increase in size, they do not expect the cost of the blade to improve much further with respect to increased WECS rating. Experience to date indicates that wood/epoxy blades offer excellent fatigue resistance.

Gifford Technologies of the United Kingdom supply wood/epoxy laminated blades to British manufacturers. Some of these blades incorporate a FRP/foam sandwich into the trailing edge of the blade to reduce weight.

In Table 6, the results of the survey of wind turbine rotor selling prices (blades, hubs, pitch mechanism) are given. The data has been reduced to a comparison of $/kW rating and $/MWh/yr at various annual

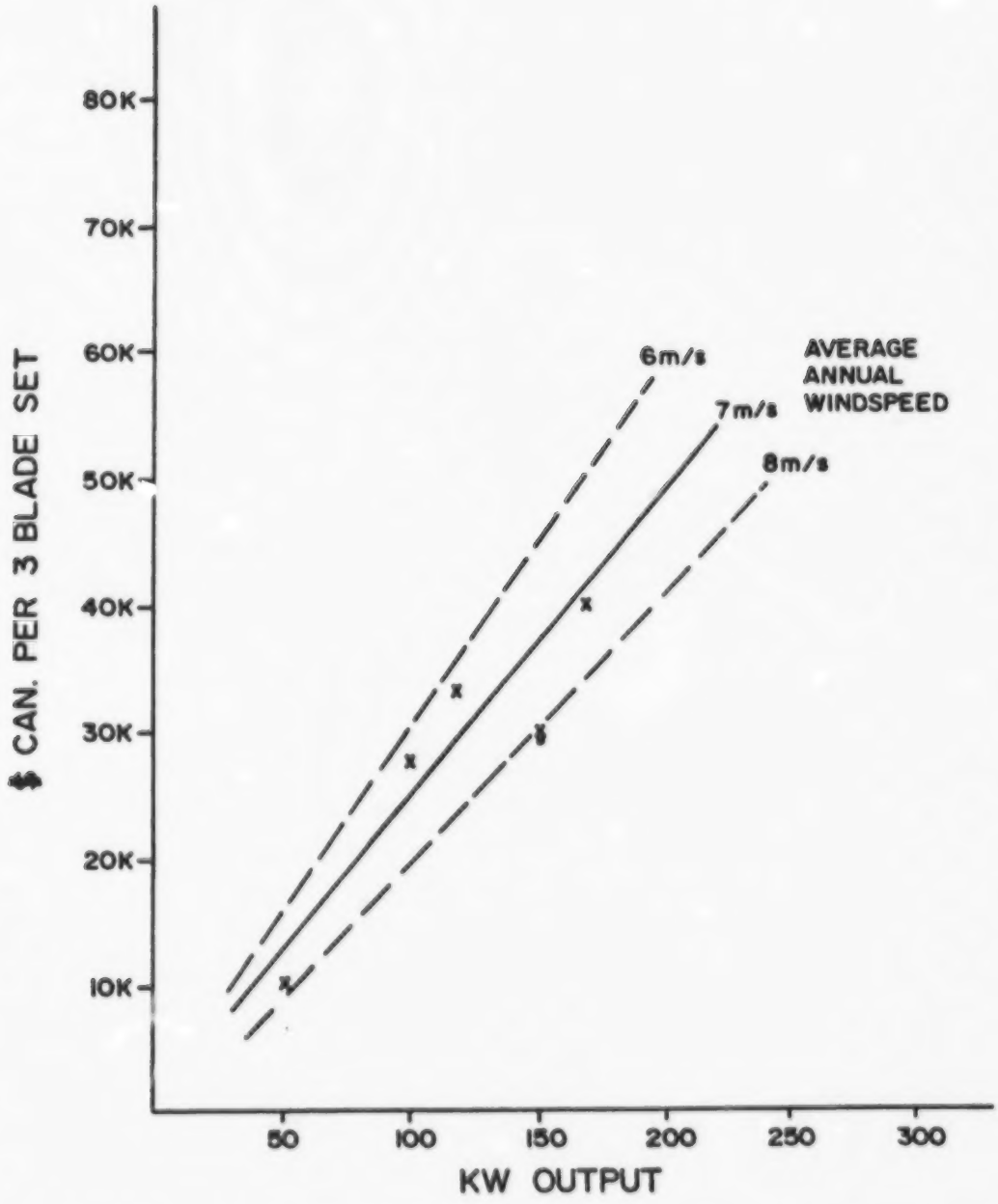

Figure 3. Selling Price of FRP Blades vs Rating

average windspeeds. Machines B through F continue to illustrate the effect of machine size and cost, although these data suggest that for the rotor assembly the economics of scale are less than for the complete WECS. Machine G uses a rotor blade pitching mechanism and FRP blades. Machine A is the largest machine and uses a laminated wood blade and full blade pitch.

TABLE 6: HORIZONTAL-AXIS WIND TURBINE
Rotor* Selling Price Versus Output

	A	B	C	D	E	F	G
Selling Price/kW Output	429	231	229	350	323	314	695
Selling Price/MWh/yr @ 6 m/s	210	101	110	142	120	168	362
Selling Price/MWh/yr @ 7 m/s	150	76	81	103	91	116	270
Selling Price/MWh/yr @ 8 m/s	116	63	65	83	75	89	217

* Includes blades, hub and pitch mechanism.

4.2 DRIVE TRAINS

4.2.1 Introduction

The WECS drive train converts the energy extracted from the wind by the rotor blades into electricity. The first element of the drive train is generally a low speed shaft which transmits energy from the rotor to the speed increasing gearbox and also resists thrust and bending loads exerted by the rotor. The gearbox is then connected by the high speed shaft to the electrical generator. A brake is usually used to stop and park the machine and may be situated on either the low speed or high speed shaft.

4.2.2 Speed Increasers

In some designs of both vertical and horizontal-axis machines, the gearbox may carry the rotor directly. Because rotors usually rotate at speeds somewhere between 40 and 100 rpm for machines in the size range reported, speed increasing gearboxes are usually necessary to increase

the rotor speed to 720, 900, 1200 or 1800 rpm as required for the generator chosen. Usually the gearbox will have two or three stages although some have only a single stage. A few machines use a multi-pole low speed alternator driven directly from the rotor that eliminates the requirement for a gearbox. Direct driven machines using a.c. alternators and connected to the grid require sophisticated excitation and synchronizing controls and are not economically attractive in sizes manufactured by the respondents. The Bergey machine uses a multi-pole permanent magnet alternator and rectifiers to charge batteries however it was considered to small to be included in this comparison.

For the machines reported there are three basic types of gearboxes generally used.

1. Planetary type with input and output shafts in line.
2. Parallel shaft with helical or spur gears and input and output shafts parallel to each other.
3. Combined spur and bevel gears with input and output shafts at right angles.

The choice of gearbox type and rating depends greatly on the design of the rotor and generator. Machines with synchronous generators exhibit higher dynamic stress during operation because of the zero slip characteristic of synchronous machines. Machines with induction generators can be designed for varying degrees of slip which allows inherent damping of loads and forces created by acceleration of the rotor during wind gusts and turbulence. The torque variations produce stresses in the gearbox and can also affect the quality of power generated. To reduce these effects, manufacturers have adopted a number of techniques which do not add significantly to cost. The designer may use flexible couplings with damping characteristics, fluid couplings, or resort to resilient mounting of the complete gearbox and generator assembly. One increasingly popular method in HAWT design is to support the weight of the gearbox and generator assembly on the low speed shaft and to couple motion of the assembly to the chassis with a resilient damping mechanism.

In horizontal-axis wind turbines, gearboxes with parallel shafts are usually employed because they allow the manufacturer to keep the overall length of the drive train as short as possible. Figure 4

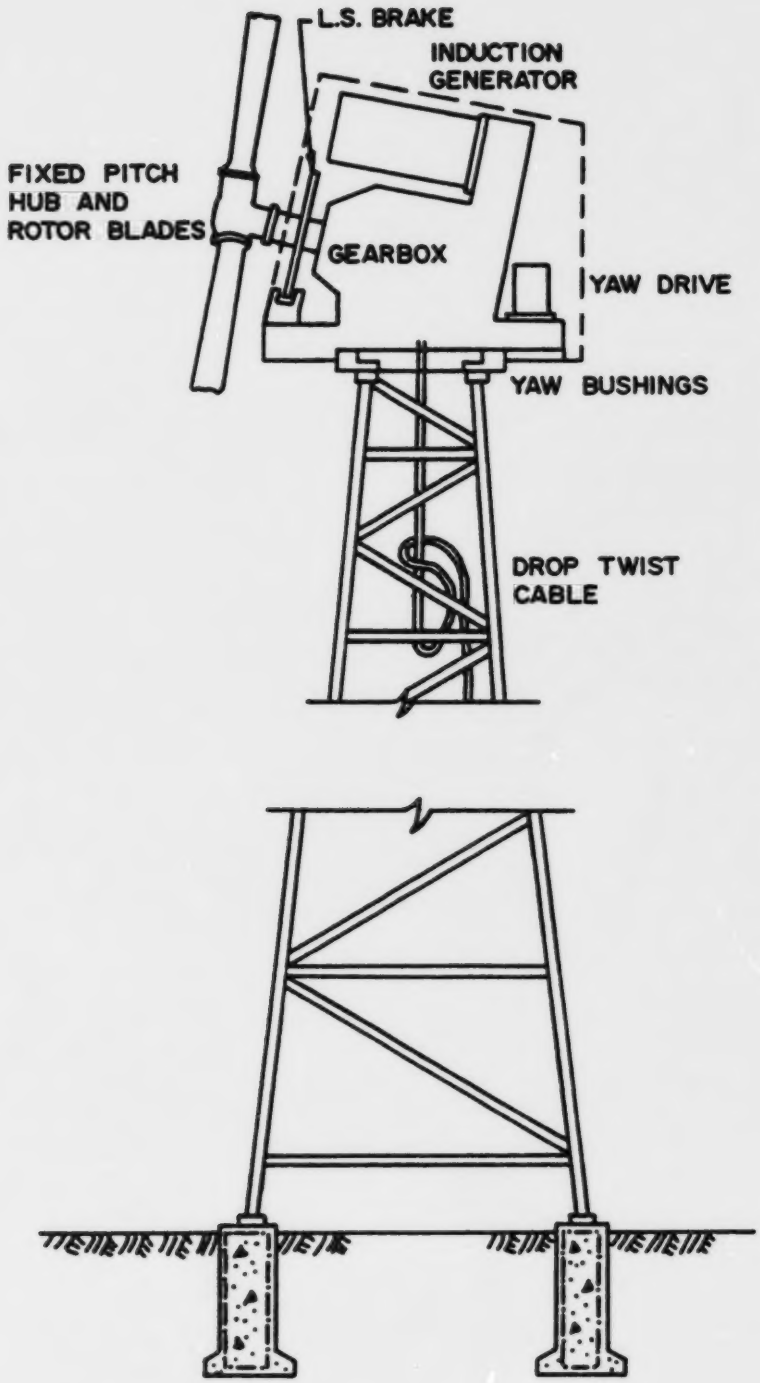

Figure 4. HAWT with Integral Gearbox and Chassis

illustrates a system where the input and output shafts are on the same end of the gearbox and the generator is flange mounted to the gearbox housing, which is the major structural element of the nacelle. This folded back offset design allows a very compact and efficient means of supporting and enclosing the drive train. Planetary gearboxes are often used with inline systems and may be designed to include the rotor support bearings.

The system brake may be located on the low speed shaft, which reduces braking stress on the gearbox, or on the high speed shaft where lower torque is present.

Table 7 compares the levelized cost of energy for the horizontal-axis drive trains. The lowest price equipment utilizes a compact folded back drive train design.

TABLE 7: HORIZONTAL-AXIS WIND TURBINE
Drive Train* Selling Price Versus Output

	A	B	C	D	E	F	G
Selling Price/kW Output	371	441	264	300	343	354	364
Selling Price/MWh/yr @ 6 m/s	181	120	127	122	127	189	190
Selling Price/MWh/yr @ 7 m/s	129	90	94	89	97	131	141
Selling Price/MWh/yr @ 8 m/s	101	74	75	71	79	100	114

* Includes Low Speed Shaft and Bearings, Speed Increaser, Brakes, Generator, and Couplings

4.2.3 VAWT Drive Trains

The VAWTS surveyed use quite different rotor supporting methods and drive trains. In the Adecon machine, the rotor is supported axially on the input shaft and thrust bearings of a two-stage right angle gearbox. The first stage of the gearbox is a parallel shaft helical gear arrangement. The second-stage is a spiral bevel arrangement which provide a horizontal output. The horizontal high speed output shaft is connected by a flexible coupling to a 150 kW, three-phase, 1800 rpm induction generator. A spring applied disc brake is located on the high speed shaft.

The Indal 500 kW machine rotor is supported directly on a large bull gear whose shaft in turn is supported by a hydraulic bearing. Pinion gears engage on opposite sides of the bull gear and provide a 16:1 speed increase to two 260 kW, three-phase, 720 rpm induction generators. Braking is provided by a set of eight brake pads mounted on the machine frame beneath the bull gear. When the turbine is operating, a pressurized hydraulic cylinder lifts the bull gear free of the brake pads enabling the rotor to rotate on a bearing comprised of the column of hydraulic oil. A similar piston and cylinder at the top of the machine provides for constant guy tension. Removal or loss of the hydraulic pressure allows the combined force of guy cable tension, rotor weight, and bull gear weight to act on the brake pads bringing the machine to a safe stop.

4.2.4 Low Speed Rotor Shafts and Bearings:

Low speed shafts in both the vertical and horizontal-axis machine serve the same basic function, to transmit power from the rotor to the speed increaser and to support the weight and thrust of the rotor. Low speed shafts for VAWTS are generally very short and an integral part of the gearbox. The low speed shaft by a typical 100-200 kW horizontal-axis machines is 170-190 mm in diameter and may be 2 m in length. The shaft is usually carried in two double spherical roller bearings.

4.2.5 Brakes

Brakes may be located on either the low or high speed shafts. The location of the brake determines to a considerable extent the design of other drive train components and the rotor as well. The location of the brake also effects safety and reliability and the requirement for overspeed protection. High speed brakes although less expensive place heavier demands on speed increaser and rotor design. As with many other design areas an iterative approach or investigation that includes cost and performance of most of the machine elements must be used to determine the most economic design. All brakes are applied by spring pressure or gravity and use fail safe electrical or hydraulic systems to hold the brake in the disengaged position and only permit rotation when the control system senses a safe operating condition.

Manufacturers of machines with outputs between 100-200 kW reported selling prices between $2,500 and $3,500 for the brake disc and calipers. Normally the brakes are used to stop the machine in regular service when commanded by the control system and are also intended for emergency use in the event of equipment failure. The brake is also used, for example, for stopping the machine when untwisting of the power cable is required. (Many machines use highly flexible twist cables instead of slip rings.) Aerodynamic tip brakes, spoilers or small parachutes are used on many European machines to protect against overspeed in case of failure of the disc brake mechanism or related components.

4.2.6 Generators

Generators for modern WECS are usually of the synchronous or induction variety. Synchronous generators are more costly then simple induction generators because their construction requires a salient pole field and associated excitation controls. Also there is a requirement for automatic synchronizing controls and associated protection. Synchronous generators, because of their constant speed also introduce other design constraints related to dynamic rotor loads and stresses which may cause overall machine cost to increase. Although solid state controls and inverters can be used to enable variable speed operation, the additional cost has not been found to be justified for the size of the machines considered in this study. Induction generators with wound rotors may also be used in conjunction with solid state frequency controls to enable variable speed operation, however, for the same reason are not commonly applied to commercial equipment.

Induction generators are much simplier and are essentially identical to induction motors. Many WECS designs use the induction generator, often at reduced voltage to motor the machine up to operating speed. They may be designed to incorporate high slip which allows operation over up to a 10% speed variation and may also incorporate dual windings to enable two speed operation. Some manufacturers incorporate this feature or use one large and one small generator to enable fixed pitch rotors to more efficiently capture the energy in low wind speeds.

One of the disadvantages of induction generators is the requirement for the connected utility to supply negative reactive power for excita-

tion. If the requirement is too large in some distribution and transmission systems an undesirable line voltage regulation or stability problem may occur which must be overcome by addition of power fractor correction capacitors to the WECS. The cost of capacitors is not high but certain safety and control precautions in their application must be observed to avoid possible self excitation.

Generators account for 24 to 30 percent of the drive train cost compared to speed increasers which account for 45 to 47 percent.

Some of the significant observations of generator cost follows:

- o Between 100 kW to 500 kW, there appears to be little economy of scale. As size doubles so does the price. Generator prices are roughly $30/kW for three-phase, 1800 rpm machines.
- o Three-phase, three pole, induction generators designed to operate at 1200 rpm cost one-third more than two pole 1800 rpm machines.
- o Induction generators with two separate windings enabling them to operate at two different speeds and outputs cost approximately 30 percent more than standard generators.
- o Volume purchasing of generators is reported to reduce generator costs by about 15 percent.

Although some manufacturers offer a choice of synchronous or induction generators, the majority use two pole induction generators with power factor correction capacitators. The lowest cost equipment in this survey use two pole induction generators with double windings to obtain two speed operation.

4.3 SUPPORT SYSTEMS

4.3.1 Introduction

The structural support system for horizontal-axis wind turbines consists generally of guyed towers or unguyed free-standing towers. Vertical-axis wind turbines most often use a guyed structure which also includes the rotor column. One manufacturer of VAWTS is however using an external steel frame to support the rotor. Although some small HAWT WECS manufacturers supply a wind turbine without a specific tower, large machines are by necessity supplied with a structural support system as an integral part of the machine. The interaction of dynamic structural

loads on the harmonic behaviour and character of the rotor, drive train and support structure can, if not carefully considered in design, result in serious cyclic loads which can seriously affect equipment life. Solutions to such problems by brute force of increasing component size and material strength can have a significant undesirable effect on equipment weight and cost.

Generally, towers are constructed of steel and may vary in style from bolted fabrications using pre-formed angle sections to tapered welded tubular sections assembled by merely stacking them together. Wooden pole towers have been used by some small manufacturers but are not recommended for larger machines. Although the majority of vertical-axis Darrieus machines currently installed use a guyed rotor structure, a recent development by Adecon Energy Systems employs a rigid external frame to support the top of the rotor. This has the effect of greatly reducing downward thrust on the rotor allowing a much lighter rotor column structure. All of the large HAWT manufacturers responding to the survey utilize an unguyed self-supporting steel tower. Those manufacturers who use guyed tubular towers often design them to be self-erecting with gin pole apparatus and winches. This eliminates the requirement for large cranes to erect machines. This technique can also be adapted to raise large free standing towers in areas where large cranes are not available.

4.3.2 Structural Support Systems for Vertical-Axis Wind Turbines

Structural support for vertical-axis wind turbines as indicated earlier is being provided by two very different techniques. Generally, however, the system can be reduced to the common elements listed below:

- o foundations and anchors
- o rotor support
- o rotor column
- o drive train support including lower rotor support and equipment enclosures

Foundation costs for VAWTS will vary considerably depending upon soil conditions and available materials. Given similar soil conditions and topography, the foundation costs for external frame support structures will be less than those for a comparably rated guyed rotor.

The difference results largely from the elimination of the static tension load in the guys.

Costs for fabrication of tubular and lattice columns for VAWTS, on a per weight basis, compare closely with those of tubular and lattice towers for HAWTS. There is however a very substantial difference in the levelized energy costs for the machines surveyed. This difference results from the much lower weight of the lattice column made possible because it is not required to support the compression load of guy cables.

It is difficult to separate costs for drive train support, rotor support, and enclosures for generation and control equipment because of the vast differences in the configuration of the two VAWTS surveyed and because of duality in various component roles. In one case for example, the rotor is supported solely by the gearbox bearings. In another, one machine requires a separate enclosure for controls, switchgear, and protection equipment, while the other has a large housing which contains generators, switchgear, controls and protection in a weather-proof environment.

Rotor support costs for each of the techniques are not vastly different on a per MWhr/yr basis because of compensating factors. The external frame is considerably more costly than the guy cables which compensates somewhat the cost of the heavier column and foundations.

4.3.3 Structural Support Systems for Horizontal-Axis Wind Turbines

The structural support systems for horizontal-axis wind turbines is considered to be composed of the following:

- o a tubular steel or lattice steel tower built on a reinforced concrete foundation.
- o a yaw system attached to the tower top to orient the rotor to the wind direction. The yaw system contains an electromechanical drive system activated by the WECS control system. Some HAWTS are downwind machines or have a tail and operate in free yaw.
- o the steel nacelle chassis is supported by the yaw system and provides a structural platform for the drive train.
- o the nacelle cover provides weather protection for the drive train. The cover is often fabricated of FRP.

In Table 8, the structural system selling price versus output for a number of HAWTS is shown. Machine F, which reaches the lowest cost to output ratio, uses a lattice type tower that is significantly less expensive than are the cylindrical steel towers. Machine B, which at lower wind speeds is even better, uses a lower cost nacelle chassis and cover.

TABLE 8: HORIZONTAL-AXIS WIND TURBINE
Structural System Selling Price Versus Output

	A	B	C	D	E	F	G
Selling Price/kW Output	605	234	288	391	408	218	443
Selling Price/MWh/yr @ 6 m/s	296	104	139	159	151	117	230
Selling Price/MWh/yr @ 7 m/s	211	78	103	115	115	80	172
Selling Price/MWh/yr @ 8 m/s	164	64	82	92	94	62	138

Selling prices per kilogram for cylindrical steel towers range from $3-4/kg while lattice towers are approximately $2.50/kg. Also, lattice towers are somewhat lighter in weight. Lattice towers are however, considered to be less aesthetically pleasing and have higher installation and maintenance costs. Tubular towers have the advantage that they can be used to house control equipment, switchgear and tools and also provide covered access to the nacelle.

4.3.3.1 Yaw System:

The yaw system orients the machine into the wind. The yaw system for machines with driven yaw is usually composed of a ring gear with a diameter approximately that of the top of the tower and fastened rigidly to the tower. The nacelle chassis rests in a bearing on the ring gear. The bearings may be comprised of a large ball or roller bearing or several segments of oilite bushing placed around the periphery of the ring gear. A pinion driven by an electric gear motor or hydraulic motor, mounted on the nacelle chassis engages with the ring gear to rotate the nacelle chassis. On free yaw machines, a large, low friction

bearing must be used. In very small machines, nylon or delrin bushings may be used. For driven yaw machines, a wind vane is used to control the yaw drive motor. Relatively high levels of column friction in the yaw drive have been found desireable to hold the nacelle chassis in place when the nacelle is not being reorientated. This reduces cyclic stress on the yaw drive gearing when the wind direction changes slightly within the allowable threshold or backlash of the yaw orientation control.

Yaw drive systems for the equipment surveyed have selling prices in the range of $5,000 to $6,300. While economies of scale and larger units may reduce cost, they are expected to have only a small effect on overall cost.

Elimination of the yaw drive system entirely can reduce cost but at the expense of additional rotor loads caused by gyroscopic or Coriolis forces created when sudden shifts in wind direction cause the machine to yaw quickly. A teetered hub may be used to reduce these stresses. The cost of a teetered hub however must be weighed against the cost of a active yaw system. Very few manufacturers have experimented with free yaw systems for larger machines and their future is felt to be limited. Downwind machines, which can be made to free yaw without a tail, can experience significant torque fluctuation and blade loads due to the shadow effect of the tower and usually employ lattice towers which are more transparent to the wind than tubular towers.

Most large HAWTS have eliminated the requirement for slip rings to conduct power and control signals from the nacelle to the ground. Instead a flexible cable is usually suspended in a large loop under the nacelle through an apperature in the nacelle chasis. A control system counts the number of twists accumulating as the machine yaws and will untwist the machine when a set number (usually about 7) occurs.

4.3.3.2 Nacelle Chasis:

The nacelle chassis is generally a welded steel frame which supports the drive train and yaw drive system. The trend in recent designs is toward fabrication from preformed steel sections which

require little work other than cutting, welding and finishing. The chassis is often galvanized instead of painted. For 100-200 kW horizontal-axis machines, the chassis selling prices are in the $3-5,000 range per machine or $4-5/kg.

In smaller free yaw machines, the gearbox case has been used as the main element of the chassis thus significantly eliminating chassis costs. In such designs the generator may be fastened directly to a flange on the gearbox. Some large machine manufacturers are beginning to realize the desirability of this concept and are now designing machines with integral gearbox chassis.

4.3.3.3 Nacelle Cover:

The final structural component is the nacelle cover. This cover on some machines when opened becomes a work platform for servicing the drive train as well as providing weather protection for the drive train components. FRP is commonly used for this purpose. Galvanized sheet steel and aluminum are also used.

5 RESULTS

Response to the survey was disappointingly low in consideration of the 30 manufacturers to whom questionnaires were sent. Although 16 firms returned confirmation of participation forms, only 9 followed through with completed questionnaires. Unfortunately, only one manufacturer of small machines in the less than 25 kW range returned a completed questionnaire. Costs reported for this machine on both a per unit weight and MWhr/year basis were much higher than for the larger machines. For this reason the machine is not included in the comparisons.

The relative quality of the responses varied widely. Of the eleven questionnaires returned, eight were very complete and provided what appeared to be well developed costs. Two of the responses were moderately well completed, one of the questionnaires appeared to have been very hastily prepared and did not provide a good breakdown of component and sub-assembly costs. In all cases where costs were reported, however, we feel assured that they are statements of the best information available to the manufacturers.

One of the manufacturers of HAWTS who submitted a well documented response provided cost information on three machines ranging in rating from 100 kW to 200 kW. The data proved to be very useful in illustrating economies of scale, size implications, cost of manufacture, and energy production.

Although we have a high level of confidence that the cost data reported was the result of an honest and conscientious effort by the manufacturers, there are several areas or sources of uncertainty in obtaining an accurate comparison between data reported.

Some manufacturers reported direct costs exclusive of overheads, selling costs, and profit, while others reported selling prices for components and assemblies as elements of a machine. Costs in some cases, were also reported in the currency of the country of origin of the machine which will cause comparisons to become less representative of fact as rates of exchange vary.

Costs were requested for a single machine with volume discount to be stated separately. Because each manufacturer quoted volume discounts for a different number of machines, some variations in the comparative costs, resulting from normalization to a common base, will be inevitable.

6 SURVEY INDICATIONS

Although the quantity of data returned by manufacturers was much less than desired and the quality in some instances caused some uncertainty in compiled cost, there are some certain conclusions that can be reached from analysis of the data.

In accordance with the requirements of agreements of confidentiality with the suppliers of data, the information that follow attempt to prevent the reader from being able to identify the source of specific data. The information does however indicate areas where efforts to reduce overall WECS costs should be concentrated. The conclusions have been reached in context of the format and component cost breakdowns used in the questionnaire.

7 SURVEY INDICATIONS: HORIZONTAL-AXIS WIND TURBINES

7.1 ROTORS

7.1.1 Blades:

All of the manufacturers surveyed used FRP or wood as the principal material for manufacturing blades. The results of cost comparisons indicate little difference in cost for the blades surveyed with some slight advantage going to wood blades. There has been considerable field experience with generally very good results to date with respect to reliability and performance for both FRP and wood blades.

One major manufacturer of wooden blades reported that at about 19 m length they think they will achieve their lowest cost. A blade of this dimension would be used on a machine that might range in output rating from 300-600 kW.

To date, wooden blades have been manufactured in sizes to 20 m length and FRP composites to 39 m. The largest wooden blade that has been considered to date is about 27 m for a machine rated at about 1000 kW.

Typically, wood blades are lighter than RFP blades for the same length. Blade shape and other machine requirements may change this situation as blade sizes increase.

As is evidenced by the continued attraction of manufacturers of HAWTS to these materials for blades, they both seem to have redeeming qualities for use as blade building material. Because of the very nearly equal cost, the ultimate yardstick will be lifetime reliability, warranty, and maintenance issues.

7.1.2 Rotor Hub:

Rotor hubs were generally of welded or cast construction and do not contribute as a major cost component of the complete rotor assembly for the machines surveyed.

7.1.3 Pitch Control or Aerodynamic Brake Mechanism:

Pitch control to regulate rotor speed or to limit power production was used in only two of the machines surveyed. In one instance, the

pitch control was passive and achieved by simple bending or torsion of rotor or blade elements by aerodynamic and centrifugal forces. In the other, the pitch mechanism consisted of electro-hydraulic devices to regulate pitch under control of a central control system. The other machines employed aerodymanic blade spoilers or tip brakes as an integral part of the blade. These spoilers are activated centrifugally and are used to protect the machine from runaway on overspeed only. One of the machines uses a small parachute for emergency shutdown.

Active pitch control mechanisms were found to add significantly to overall rotor cost and are thus not used by many manufacturers. Stall-regulated rotors with tip spoilers for emergency shutdown are most popular because of their lower cost and simplicity.

7.1.4 Preferred Rotors:

The lowest cost rotor assembly was found to be one which consisted of a cast or welded steel rotor hub with three fixed pitch FRP or laminated wood/epoxy blades employing stall regulation to limit rotor output and tip spoilers to provide overspeed protection.

7.2 STRUCTURAL

7.2.1 Foundations:

Foundation costs were not well detailed by the respondents with the explanation that these costs are highly influenced by site conditions. All of the HAWT machines included in the survey use free standing towers without guys. Foundations are thus generally of a similar design requiring a large mass of reinforced concrete. Cost of such structures is not likely to vary greatly from manufacturer to manufacturer but will vary with site costs, materials and labour, and with varying soil and climatic conditions.

In general the cost of foundations increases directly with WECS rating for the same structural style. This is particularly evident when the supplier is required to design and guarantee performance of the system. A general trend has been noted that suppliers over specify foundation requirements and underestimate foundation costs unless they are required to supply them.

7.2.2 Guy Cables:

None of the HAWT machines included in the survey used guy cables and thus no comparisons were made.

7.2.3 Guy Anchors:

None of the machines included in the study used guy anchors and thus no comparisons were made.

7.2.4 Towers:

All of the HAWT respondents except one reported that they used a sectionalized, tubular, welded steel tower to support the machine. The other manufacturer usually supplies his machine with a lattice tower. The lattice tower is considerably less expensive even with labour required for assembly included.

There was not a significant variance among tubular column costs and it appears that there is a preference for this type of construction. The preference appears to be because of visual aesthetics and because tubular towers also provide space for control equipment and an enclosed access to the nacelle in larger machines. Since most rotors operate upwind, tower shadow is not a problem with tubular towers.

7.2.5 Yaw System:

All of the respondents reported that their machine use an active yaw drive mechanism to orient the machine into the wind. Generally, the system is an electric gear motor drive engaging a large stationary ring gear mounted on the tower top. Bearings are generally comprised of several segments of oilite bearing material riding directly on the face of the ring gear. The friction caused by this type of bearing prevents the WECS from free yawing against the yaw drive train backlash thus minimizing dynamic loads which would otherwise be present.

7.2.6 Nacelle Chassis:

All of the HAWT manufacturers surveyed use a welded steel nacelle chassis or bedplate. Costs varied significantly. Discussions with manufacturers provided information that the size and complexity of the chassis is being reduced rapidly as confidence in design improves.

Weight savings of as much as 50 percent have recently been made. Much of the savings result from changes in equipment layout and techniques of supporting gearboxes, generators, and brake mechanisms.

7.2.7 Aerodynamic Nacelle Covering:

All of the machines reported used a steel or FRP nacelle covering. Some of the steel nacelles use sound-absorbing material fastened to the cover to reduce noise. There was little difference in the cost of covers. Larger machines have fixed covers with inside access to the equipment. Some smaller machines have hinged covers which allow working space when opened. Smaller machines with compact equipment layout provide permanent or portable work platforms.

7.2.8 Preferred Structure:

Generally, the lowest cost structure is a lattice tower with individual foundation piers for each leg. The nacelle chassis preferred is manufactured of weldments of pre-formed structural steel sections. The yaw bearing preferred is a high friction bearing block type for zero backlash in the yaw drive train. Preferred nacelle coverings are manufactured of FRP and provide for safe access and service to equipment enclosed. A twist cable for conduction of power to the ground is used.

7.3 DRIVE TRAIN

7.3.1 Low Speed Shaft, Bearings, and Couplings:

Costs reported for low speed shaft assembly varied considerably. The relationship between these components and the overall design of the drive train makes separate evaluation of this component difficult. Often in recent designs the low speed shaft is an integral part of the speed increaser. The type of gearbox, brake, and arrangement or support of drive components has greater influence on cost.

7.3.2 Brake Assembly:

Disc brakes are common on both the low speed shaft and on the high speed generator shaft. Brakes in all cases are spring activated with electrical or hydraulic retention in the off state. Brakes on the high

speed shaft are lower in cost but offer somewhat reduced protection in the event of a gearbox or coupling failure. Brakes on the high speed shaft also cause higher gearbox loads during braking. None of the machines surveyed used dynamic or regenerative braking techniques.

7.3.3 Speed Increaser:

All of the machines surveyed used speed increasers with parallel shafts and usually with straight cut gears. Only one manufacturer used a gearbox with helical cut gears.

Some gearboxes were splash lubricated gearboxes while others used forced lubrication and cooling fans. Methods of coupling the gearbox to the low speed shaft varied from flanged gear couplings to keyless shrink collars. Various gearbox mounting systems are employed to reduce alignment problems. One manufacturer mounts the rotor directly on the low speed shaft and bearings of the gearbox which are strengthened to accommodate this load.

7.3.4 High Speed Coupling:

All of the manufacturers except one reported the use of a flexible coupling between the gearbox and generator. The couplings usually were of the rigid rubber or gear type. The exception used a flange mounted generator directly on the gearbox case.

7.3.5 Generator:

There is considerable variation in the design of generators used. Some manufacturers used two separate generators operating at slightly different speeds to improve overall energy capture of the WECS. Others accomplish the same end with dual windings in the generator to obtain more efficient operation at lower windspeeds. Some others use a single rated generator. All of the manufacturers surveyed, the generator used was the induction type. In dual generator systems the smaller induction generator was used as the starter motor. None of the machines used a separate starting motor.

7.3.6 Preferred Drive Trains:

Drive trains are the most significant cost element and designs vary widely from machine to machine. Recent history of the designs reported

show a rapid progression towards lower cost manufacture. The most attractive design appears to be comprised of a drive train with combined support of the low speed shaft and gearbox allowing foreshortening of the nacelle chassis by mounting the generator adjacent to and parallel to the main shaft. High speed shaft brakes are becoming more common. Overspeed blade tip spoilers offer satisfactory safety and performance. Induction generators in the range of sizes reported are the most attractive. Dual windings or dual generators are both attractive to increase energy capture and reduce starting loads.

8 SURVEY INDICATIONS: VERTICAL-AXIS WIND TURBINES

8.1 ROTORS

8.1.1 Blades:

Both of the VAWT manufacturers responding utilize extruded aluminum blades as do two other U.S. manufacturers. Aluminum blades have also been fabricated for a 500 kW experimental machine being erected at Bushlands, Texas by the U.S. DOE. One of the limitations of this technology is that the maximum extrusion dimension possible today is about .75 m. This limit restricts the size of machine which may be constructed using simple single extrusions. This limitation in size may be overcome by bonding individual extruded sections to make a large section or by using some other fabrication technique. So far there is little experience with other technologies for VAWT blades. Although consideration has been given to both wood/epoxy and FRP because of their resistance to fatigue there have been no known efforts to fabricate blades for machines in the 50 - 500 kW range using these techniques. Since blade cost is very dependent on weight there is an obvious desire to reduce weight.

8.1.2 Columns:

Columns for VAWTS are either of tubular or lattice type steel construction. Depending on the loading they must withstand they may vary widely in strength and weight. The loading depends to a large extent on how the rotor is supported.

8.1.3 Other Rotor Components:

VAWTS have few major rotor components other than blades and columns. Struts are commonly used to reduce the bending load on the blade root. They also reduce flatwise deflections of the blade when running and when parked in a high wind. Hinging of the blade to the column at the root is also being considered to reduce blade bending moment at the blade root. The cost of these components is not a very significant proportion of rotor cost and thus little opportunity exists to effect a significant direct cost reduction in this area.

Spoilers have largely been eliminated as a means of overspeed control. Instead redundancy in braking control and brake apparatus is being employed to provide for safe operation. Because the brake can be located at the base of the machine, its weight is not of great structural concern.

8.2 STRUCTURAL

The distribution between and relative magnitude of cost for rotor, support and foundation components is greatly influenced by the choice of guyed or external frame design for the support system. The indication obtained from analysis of the data supplied to this study is that the levelized cost of energy using the space frame concept could be as little as 1/3 of that for a guyed system. There are, however, several other significant design differences in the rotor and drive train that contribute to this apparently wide variation.

8.2.1 Foundations:

Although foundation requirements for all WECS are very dependent upon site conditions the data supplied indicates that the cost for foundations for the external space frame will be less than for conventional guyed rotor Darrieus machines.

8.2.2 Support Systems:

Support systems for two VAWT systems vary too widely in design to enable identification of indications toward preference for individual components. An overall indication is, however, very obviously in favour of the external frame, light weight design. It must be recognized,

however that this indication is based on design data and information only and that there is insufficient data with regard to actual performance, reliability, and operation to confirm this indication.

8.3 DRIVE TRAIN

Drive trains for VAWTS being located at the base of the machine do not generally pose a weight or space problem. The two VAWTS surveyed used very different drive train designs having a great difference in cost.

A comparison of the cost of the drive train components and the estimated energy production indicates that the lowest cost can be obtained by using commercially available speed increasing gearboxes and other components instead of custom manufactured drive train components. The advantage in cost of the former appears to be as great as 3 to 1 on a levelized cost basis. The cost of the drive train is also related to the weight of the rotor supported which is also greatly different between the two designs.

8.4 GENERAL INDICATIONS FOR VERTICAL-AXIS WIND TURBINES

Although comparison of the two designs is difficult because of the great difference in concept and the lack of confirmed performance information from the Adecon machine it is evident that improved cost lies in the direction of reduced weight and use of commercially available components.

Also it appears evident that the elimination of guy tension loads can lend to significantly reduced rotor weight and other structural loads.

9.0 CONCLUSIONS

Costs of WECS during the past decade have reduced dramatically and reliability has increased reciprocally. Mature HAWT designs are being advertised at uninstalled capital costs that promise to produce electrical power at a levelized cost of less than $.300/MWhr/yr at a site with an average annual wind speed of 7 m/s. Even if this figure is doubled for installed system the energy cost is less in many parts of

Canada than that for any other new generation. The study indicates that there are many areas in which cost reduction by manufacturer may be achieved. This conclusion has been confirmed in discussion with designers and by observation of trends toward lighter and more efficient mechanical and aerodynamic designs. It is evident that the reduction signals sent via the reduction of tax and other incentives in the worlds major market for wind farm machines in California have been responded to by industry. It is also evident that industry recognize the potential for selling machines into the new disperse market at remote and individual sites where costs of energy and other conditions favour WECS application.

Analysis of the cost data and other information provided and intrepretation of subsequent discussions with manufacturers tempered with judgement based on the experience of the study team leads us to the conclusions that follow.

Wind turbines are still at an early stage of design and will undergo major changes to reduce weight, improve materials and increase efficiency. Although no respondents provided detailed information regarding their plans in this regard for reasons of privacy, and their own uncertainty before the fact, there is an indicated trend toward some specific designs as described in the foregoing sections 7 and 8 giving survey indications.

HAWT designers will migrate toward combined drive train/chassis designs mounted on truss type towers. Rotor design will move to either more expensive but longer life FRP blades or towards wood/epoxy composites. Rotors will probably remain fixed pitch with aerodynamic overspeed brakes and may use solid state switching systems to improve efficiency and reduce torque transients.

HAWT sizes will continue to increase for the wind farm market and will probably settle at between 300 and 600 kW. Smaller, more expensive machines will persist for the remote community and individual market.

Conclusions regarding VAWT designs are more difficult to reach because of limits in the information available. It does, however, appear evident that significant cost reduction is possible and that costs can be competitive with HAWT technology. It also appears evident

that design emphasis on light weight and use of commercially available components will achieve lowest cost. Rotors may continue to be fabricated of aluminum but may be designed for longer life by consideration of mounting techniques and finishings. Other materials may also be considered for blade manufacture. An external frame that enables reduced weight of the rotor and other drive train components seems desirable.

VAWTS will not increase dramatically in size and will probably settle out at between 500 - 1000 kW and be intended primarily for wind farm application.

Resource Ventures Incorporated

March 27, 1986

_____
_____
_____
_____

Attention: Engineering Manager

Gentlemen:

The government of Canada through its Department of Energy, Mines, and Resources (EMR) has a major interest in the continued development and application of wind energy conversion systems (WECS). This interest is a result of a need to improve the efficiency and economics of producing energy in many remote northern and coastal communities of Canada where conventional supplies of electricity are very expensive. EMR anticipate a rapid growth in demand for lower cost electricity in these communities where wind energy offers an exciting alternative. They wish to investigate the practical and economic application of WECS as an alternative to diesel-generated electricity and to obtain information regarding present and future costs of WECS equipment so they may determine what direction should be taken regarding research, demonstration, and incentive programs, and whether to manufacture or buy. To this end, EMR have commissioned a study to determine WECS costs and prospects for cost reduction.

We are pleased at Resource Ventures Incorporated (RVI) to have been selected as the study consultants. As operators of the Atlantic Wind Test Site (AWTS) in Canada, we have considerable experience in the evaluation of WECS and related technology. RVI is, in addition to operating the AWTS, a private, independent consulting organization that has no vested interest in, or association with, any specific manufacturer or industry. Participants other than myself will be Stewart Bennie, our economic and business consultant, and Carl Brothers, a professional engineer and our operations manager at the AWTS.

Our objective in the study is to provide EMR with the information they require using a methodology or process that gathers the necessary data from you and other manufacturers, suppliers, and operators without disclosing the source of data and information that you consider of a confidential nature. To achieve this goal, we will use a technique of gathering data and a process of analysis, presentation, and publication

of results that will guarantee the confidentiality of the information you may supply. I trust that you will consider that the enclosed certificate of non-disclosure and the process described with the enclosed study questionnaire will protect your interests.

It is, of course, expected that the questionnaire will require some time and effort on your part and that of your colleagues. In exchange for your cooperation and participation, we will provide you with a full copy of the final report which, within the proposed constraint of confidentiality of information, will enable you to compare your data against the range of other data and information presented.

The questionnaire is largely self explanatory, thus only brief instructions are provided. If, however, you wish further elaboration on any matter, please do not hesitate to contact one of the undersigned. We shall be attempting to visit as many respondants as possible during the next few weeks. To enable us to plan our visits, please return the confirmation of participation form as soon as possible after deciding whether you wish to participate. We hope you will find it possible to participate with us in the study and look forward to meeting with you in the immediate future.

Please direct inquiries to:

Malcolm Lodge
Wind Program Manager
49 Pownal Street, 2nd floor
Charlottetown, PE
(902) 892-0361
Telex: 014-44154

Stewart Bennie
Executive Director
49 Pownal Street, 2nd floor
Charlottetown, PE
(902) 892-0361
Telex: 014-44154

Sincerely,

Malcolm A. Lodge, P. Eng.
Wind Program Manager

rm
Enclosures
RVI: 222

MEMORANDUM

TO: _____ - Attention: Engineering Manager

FROM: Malcolm A. Lodge, Wind Program Manager

RE: Project Questionnaire for a Study on Wind Energy Conversion Systems Cost Evaluation and Prospects for Cost Reduction

The attached questionnaire if completed fully will provide us with the data and information we require to carry out this study. If you are able to participate, please fill in the questionnaire as completely and as accurately as possible. Also whether you participate or not, please complete and return the enclosed confirmation card to us as soon as you make your decision.

You may feel that the questionnaire is rather detailed; however, we beg your indulgence and understanding that such detail is desireable to assist us to effectively catagorize and combine data.

When completing the questionnaire, please circle in RED any data or information that you consider to be of a sensitive nature and that you do not want to be identifiable or traceable to your company's products. While prices have been shown in dollars, it may be simpler for you to quote in your currency and leave it to us to convert to Canadian dollars.

When completing the questionnaire, please note that we have asked for your consideration of very cold weather and marine environment operation. If you are able, please indicate what changes you feel would be required in each sub-assembly and the effect that might have on the price of the assembly. For example, Price increased by 20 percent.

Generally, the technique that we will use to camouflage data and information will be to normalize and classify data into ranges in regard to identifiable parameters and descriptions such as ratings, dimensions, tower heights, component weights, and cost. An example of a typical chart is attached illustrating the manner in which most data will be presented.

When you have completed the questionnaire, please return it by courier COLLECT to us using the enclosed mailing label.

Thank you for your attention to this request. We hope you will be able to participate and assist us to obtain as large a sample of data as possible to enhance the value of the study both to our client, EMR, and to you by providing a broad base of cost and potential cost reduction information.

CONFIRMATION OF PARTICIPATION

Energy, Mines, and Resources Canada Wind Energy Conversion Systems (WECS) Cost Evaluation and Prospects for Cost Reduction Study.

Please complete and return as soon as possible to:

Resource Ventures Incorporated
49 Pownal Street, 2nd floor
Charlottetown, Prince Edward Island
CANADA
C1A 3W2

[] We wish to participate.

[] We will be available should you wish to visit us.

[] We will not be participating for the following reasons:

_____

_____

_____

Company Name _____

Contact Name _____

QUESTIONNAIRE INSTRUCTIONS

1. Resource Ventures Incorporated will respect the confidentiality of the information supplied by manufacturers; however, not all of the information included in this questionnaire is confidential. To assist us in maintaining confidentiality of the sensitive data, would you please underline or circle in RED ink the particular information that must be kept confidential. For example, the single machine price of a wind turbine is not likely to be confidential, but the discount on quantity sales or the component prices are likely to be confidential. Therefore, this information should be identified as indicated.

2. The sum of component prices should equal the single machine selling price as in the price summary at the end of the questionnaire.

3. Not all sections of the questionnaire are directly related to the responsibilties of the manufacturer and are not normally included in the selling price of the machine. Information on these costs, if available, would be helpful in developing the installed cost of the machine.

GENERAL QUESTIONNAIRE

MANUFACTURERS' DATA

(a) Manufacturer's Name _____

(b) Address _____

_____

_____

_____

(c) Telephone Number _____

(d) Company Officals to Contact _____

_____

#1 WECS:

Product Name _____ Model #_____

Single Machine Selling Price $_____ FOB/Factory_____

General Selling Conditions _____

_____

_____

Typical Volume Discounts _____

_____

_____

Design Operating Conditions :

Min. Temp. _____°C(°F) Max. Temp. _____°C(°F)

Marine Environment Restrictions _____

_____

_____

Icing Conditions Restrictions _____

_____

_____

HAWT _____ VAWT _____ Operating RPM. _____

Cut-in Speed _____m/s(mph)

Rated Output _____kW at _____m/s(mph)

Cut-out Speed _____m/s(mph)

If HAWT:

Upwind _____ Downwind _____

Rotor Diameter _____m(ft.) Hub Height _____m(ft.)

If VAWT:

Swept Area _____m^2($ft.^2$) Column Height _____m(ft.)

Approximate 1985 Volume:

10 _____

10- 60 _____

61- 150 _____

151- 500 _____

501-1000 _____

1000 _____

Performance Curve (please attach)

Machine Availability _____

References:

Machines _____

Location _____

Period _____ to _____

Recorded Availability _____

Operating and Maintenance Costs _____ $/unit/year

or _____ $/ kW./year

In Canada's remote communities, a wind turbine will experience:

(a) minimum operating temperatures of -50°C (-58°F) and maximum temperatures of 30°C (86°F);

(b) icing conditions; and

(c) marine environment (salt).

Will This Machine Operate in These Conditions _____

_____

Can This Machine Be Modified to Meet These Conditions _____

_____

In Modifying This Machine to Meet These Conditions, What Effect Do You Expect This Will Have on:

(a) Selling Price _____

_____

_____

(b) Performance _____

_____

_____

#2 WECS:

Product Name _____ Model #_____

Single Machine Selling Price $_____ FOB/Factory_____

General Selling Conditions _____

_____

_____

Typical Volume Discounts _____

_____

_____

Design Operating Conditions :

Min. Temp. _____°C(°F) Max. Temp. _____°C(°F)

Marine Environment Restrictions _____

_____

_____

Icing Conditions Restrictions _____

_____

_____

HAWT _____ VAWT _____ Operating RPM. _____

Cut-in Speed _____m/s(mph)

Rated Output _____kW at _____m/s(mph)

Cut-out Speed _____m/s(mph)

If HAWT:

Upwind _____ Downwind _____

Rotor Diameter _____m(ft.) Hub Height _____m(ft.)

If VAWT:

Swept Area _____m^2($ft.^2$) Column Height _____m(ft.)

Approximate 1985 Volume:

10 _____

10- 60 _____

61- 150 _____

151- 500 _____

501-1000 _____

1000 _____

Performance Curve (please attach)

Machine Availability _____

References:

Machines _____

Location _____

Period _____ to _____

Recorded Availability _____

Operating and Maintenance Costs _____ $/unit/year

or _____ $/ kW./year

In Canada's remote communities, a wind turbine will experience:

(a) minimum operating temperatures of -50°C (-58°F) and maximum temperatures of 30°C (86°F);

(b) icing conditions; and

(c) marine environment (salt).

Will This Machine Operate in These Conditions _____

_____

Can This Machine Be Modified to Meet These Conditions _____

_____

In Modifying This Machine to Meet These Conditions, What Effect Do You Expect This Will Have on:

(a) Selling Price _____

_____

_____

(b) Performance _____

_____

_____

QUESTIONNAIRE

HORIZONTAL-AXIS WIND TURBINE

COMPONENT CLASSIFICATION (COMP. CLASS. ___)

(1) Buy component fully assembled.

(2) Buy component parts and assemble in own factory.

(3) Manufacturing process cost (not assembly) equal to less than 50 percent of the value of the component.

(4) Manufacturing process cost (not assembly) equal to more than 50 percent of the value of the component.

A. ROTOR ASSEMBLY

(i) Blades: Comp. Class. _____

Price: $_____each Weight ea._____/kg(lbs.) No._____

To include: the blades, aerodynamic spoilers, blade-mounted brackets, etc. to attach blades to rotor hub or pitch control mechanism.

Characteristics:

Description _____

_____

_____

_____

Blade Length _____

Blade Chord at Root _____ At End _____

Blade Profile (NACA no.) _____

Blade Straight or Twisted _____

Blade Construction _____

_____

_____

Aerodynamic Spoiler _____

_____

Special Coatings or Finishes _____

_____

Other _____

_____

(ii) Rotor Hub: Comp. Class. _____

Price: $_____ Weight _____kg(lbs.)

To include any brackets or fittings for attaching blades or pitch control mechanism.

Characteristics:

Description of Hub and Hub to Blade Connection _____

_____

_____

_____

(iii) Pitch Control or Aerodynamic Brake Mechanism: Comp. Class. _____

Price: $ _____ Weight _____kg(lbs.)

To include the electromechanical and/or hydraulic components and any parts or mechanisms exclusively devoted to this function.

Characteristics:

Description of Pitch Control Mechanism and/or Aerodynamic Brake _____

_____

_____

_____

_____

B. STRUCTURAL

(i) Foundation:

Price: $_____

Volume of Concrete _____m^3(yd^3) Cost _____$/$m^3$($/yd^3)

To include excavation, forms, reinforcing concrete, anchor bolts, back filling. Maximum allowable bearing pressure is 150 kN/m^3 (3000 psi). Frost penetration is assumed to be 1 m (3 ft.).

Characteristics:

Description _____

_____

_____

_____

_____

(ii) Guy Cables: Comp. Class. _____

Price: $_____/ea. Weight ea._____kg(lbs.) No. of Guys _____

To include the wire cable or rods, the appropriate terminations, turn buckles, or other tensioning devices. Assumes flat site.

Characteristics:

Cable or Rod Size _____

Specification _____ Length of Cables_____

Type of Terminations _____

Method of Tensioning _____

Static Tension _____kg(lbs.) Design Load _____kg(lbs.)

(iii)Guy Wire Anchors: Comp. Class. _____

Price: $_____/ea. No. of Anchors _____

To include if applicable, excavation forms, reinforcing, concrete or anchors.

Characteristics:

Type of Anchor (footing, pier, grout column, earth anchor, rock anchor, and deadman) _____

Anchor dimension _____

(iv) Tower: Comp. Class. _____

Price: $_____ Weight _____kg(lbs.)

To include all tower parts from foundation to yaw mechanisms (ie. ladders, platforms, etc.)

Characteristics:

Steel Pole Tower _____ Wood Pole Tower _____

Structural Steel _____

Other _____

_____

Height of Tower (foundation to yaw mechanism) _____

Size at Base _____ X _____ or Diameter _____

Size at Top _____ X _____ or Diameter _____

Wall Thickness _____ or Size of Structural Members

_____

Description _____

_____

_____

_____

(v) Yaw System: Comp. Class. _____

Price: $_____ Weight _____kg(lbs.)

To include bearings, shafts, ring gears, pinions, yaw drive (including electric or hydraulic system), and brake (do not include controls if part of auto control system).

Characteristics:

General Description _____

_____

_____

_____

Description of Key Parts _____

_____

_____

_____

_____

(vi) Nacelle Chassis: Comp. Class. _____

Price: $_____ Weight _____kg(lbs.)

Includes chassis and supports for low speed shaft, bearings, support for speed increaser, and generator.

Characteristics:

Description_____

_____

_____

_____

(vii)Aerodynamic Nacelle Covering: Comp. Class. _____

Price: $_____ Weight _____kg(lbs.)

Includes spinner, ring, and nacelle covering.

Characteristics:

Description (Include Materials)_____

_____

_____

_____

C. DRIVE TRAIN

(i) Low Speed Shaft, Bearings, and Coupling: Comp. Class. _____

Price: $_____ Weight _____kg(lbs.)

Characteristics:

Low Speed Shaft Material _____ Size _____

Bearings Description _____

_____

_____

No. _____ Size _____

Coupling Description _____

_____

Size _____

(ii) Brake Assembly: Comp. Class. _____

Price: $_____ Weight _____kg(lbs.)

To include brake drum or disc rotor, brake shoes or calipers, hydraulic cyclinders, and drive. If dynamic brake used include cost of components.

Characteristics:

Description _____

_____

_____

Location of Brake (highspeed or lowspeed shaft) _____

_____

Brake Drum or Disc Rotor Dimensions _____

No. of Drums or Disc Rotors _____

Total Shoe or Caliper Pad Area _____$cm^2(in^2)$

Activation of Brake _____

_____

(iii) Speed Increaser (gearbox or other): Comp. Class. _____

Price: $_____ Weight _____kg(lbs.)

Characteristics:

Description _____

_____

_____

Input RPM _____ Output RPM _____

Rated Low Speed Torque _____

No. of Stages _____

Nominal Power Rating _____

Custom Design _____ Stock Design _____

(iv) High Speed Coupling: Comp. Class. _____

Price: $_____ Weight _____kg(lbs.)

Characteristics:

Size of Coupling _____

Type of Coupling _____

_____

(v) Generator #1: Comp. Class. _____

Price: $_____ Weight _____kg(lbs.)

Characteristics:

Type _____

_____

Power _____ Voltage _____

Phase _____ Hertz _____

Full Load Torque _____ NEMA Type _____

Insulation Class _____ Enclosure _____

Generator #2: Comp. Class. _____

Price: $_____ Weight _____kg(lbs.)

Characteristics:

Type _____

_____

Power _____ Voltage _____

Phase _____ Hertz _____

Full Load Torque _____ NEMA Type _____

Insulation Class _____ Enclosure _____

Starter Motor: Comp. Class. _____

Price: $ _____ Weight _____kg(lbs.)

Characteristics:

Type _____

_____

Power _____ Voltage _____

Phase _____ Hertz _____

Full Load Torque _____ NEMA Type _____

Insulation Class _____ Enclosure _____

(vi) Lubrication System: Comp. Class. _____

Price: $_____ Weight _____kg(lbs.)

Characteristics:

System Description: _____

_____

_____

_____

_____

(vii) Miscellaneous: Comp. Class. _____

Price: $_____ Weight _____kg(lbs.)

To include guards, covers, seals, and miscellaneous hardware.

Description _____

_____

_____

D. ELECTRICAL

(i) Generator Accessories: Comp. Class. _____

Price: $_____ Weight _____kg(lbs.)

To include main contactor, starting switchgear, power factor correction, exciter control, intercabling enclosure, assumed to be factory assembled.

Characteristics:

Description _____

_____

_____

_____

_____

Instruments Supplied _____

Type of Enclosure _____

(ii) Controls: Comp. Class. _____

Price: $_____ Weight _____kg(lbs.)

To include mircro-processors, anemometers, modems, safety devices (vibration sensors), monitoring equipment, relays, starter controls (include remote), and control wiring.

Characteristics:

Systems Description _____

_____

_____

_____

_____

_____

_____

_____

(iii) Miscellaneous Electrical: Comp. Class. _____

Price: $_____ Weight _____kg(lbs.)

To include space lighting, top lighting, outlets, transformers, etc.

Characteristics:

Description _____

_____

_____

(iv) Lightning Protection: Comp. Class. _____

Price: $_____ Weight _____(kg)lbs.

To include rods, wire cable, grounding.

Characteristics:

Description _____

_____

_____

_____

(v) Slip Rings: Comp. Class. _____

Price: $_____ Weight _____(kg)lbs.

Characteristics:

Description (Include Materials)_____

_____

_____

_____

E. PACKAGING FOR SHIPMENT

Price: $_____

Description _____

_____

_____

F. ON SITE ASSEMBLY, ERECTION, AND CONNECTION

Description of Manufacturer's Responsibility _____

_____

_____

_____

_____

Description of Buyer's Responsibility _____

_____

_____

_____

_____

(i) Assembly Labour (excluding electrical):

Price: $_____ (Man hours _____: $/hr. _____)

To include unloading at site and site assembly.

(ii) Equipment:

Price: $_____

a. Type of Equipment _____

Leased _____ Owned _____

Machine hours _____: $/hr. _____

b. Type of Equipment _____

Leased _____ Owned _____

Machine hours _____: $/hr. _____

c. Type of Equipment _____

Leased _____ Owned _____

Machine hours _____: $/hr. _____

(iii) Electrical Labour (connected with machine assembly and erection):

Price: $_____ (Man hours _____: $/hr. _____)

(iv) Electrical Connection to Utility:

Price: $_____

To include labour and materials to install cable in conduit from switchgear to disconnect to metering cabinet to transformer.

Describe Installation _____

_____

_____

_____

(v) Site Improvements: (Assumes level site)

Price: $_____

To include site leveling, roads, fences, etc.

Description _____

_____

_____

_____

_____

_____

G. COMMISSSIONING

Price: $_____

Who performs this work _____

(i) Labour:

Man hours _____: $/hr. _____

(ii) Expenses:

$/day _____: days _____

H. REMOTE SITE ERECTION OF EQUIPMENT

Price: $_____ Weight _____kg(lbs.)

To include winches, A-frames, gin poles, cables, blocks, etc.

Description _____

_____

Is Equipment Left at Site _____

I. MANUFACTURERS' WARRANTY

(i) Standard Warranty:

Price: $_____

Description _____

_____

_____

_____

_____

What Parts:	What Time Period:
_____	_____
_____	_____
_____	_____
_____	_____
_____	_____
_____	_____
_____	_____

(ii) Extended Warranty:

Price: $_____

Description _____

_____

_____

_____

_____

What Parts:	What Time Period:
_____	_____
_____	_____
_____	_____
_____	_____
_____	_____
_____	_____
_____	_____

(iii) Optional Warranties eg. guaranteed availability:

Price: $_____

Description _____

_____

_____

_____

_____

_____

HORIZONTAL-AXIS WIND TURBINE

Price Summary

A. Rotor Assembly:

(i) Blades $_____

(ii) Blade Hub _____

(iii) Pitch Control or Aerodynamic Brake _____

$_____

B. Structural:

(i) Foundation $_____

(ii) Guy Cables _____

(iii) Guy Anchors _____

(iv) Tower _____

(v) Yaw System _____

(vi) Nacelle Chassis _____

(vii) Aerodynamic Nacelle Covering _____

_____

C. Drive Train:

(i) LowSpeed Shaft,Bearings& Coupling $_____

(ii) Brake Assembly _____

(iii) Speed Increaser _____

(iv) High Speed Coupling _____

(v) Generator #1 $_____

Generator #2 _____

Starter Motor _____

_____

(vi) Lubrication System _____

(vii) Miscellaneous _____

_____

D. Electrical:

(i) Generator Accessories $_____

(ii) Controls _____

(iii) Miscellaneous Electrical _____

(iv) Lightning Protection _____

(v) Slip Rings _____

_____

SUBTOTAL TO NEXT PAGE $_____

SUBTOTAL FROM PREVIOUS PAGE $_____

E. Packaging for Shipment _____

F. On-Site Assembly, Erection, and Connection:

(i)	Assembly Labour	$_____
(ii)	Equipment	_____
(iii)	Electrical Labour	_____
(iv)	Electrical Connection to Utility	_____
(v)	Site Improvements	_____

_____

G. Commissioning:

(i)	Labour	$_____
(ii)	Expenses	_____

_____

H. Remote Site Erection Equipment _____

I. Manufacturers' Warranty (Standard Warranty) _____

TOTAL SELLING PRICE (For a Single Machine) $_____

CERTIFICATE OF NON-DISCLOSURE

THIS CERTIFICATE OF Non-Disclosure made this 20th day of March, 1986

BY: Resource Ventures Incorporated
of Charlottetown, P.E.I.

TO: _____

_____

(hereinafter called the Company)

INSOFAR AS RESOURCE Ventures Incorporated wish to obtain specific data and information from the Company for the purposes of studying, analyzing, and predicting the current and future cost of wind energy conversion systems and component parts of wind energy conversion systems, and insofar as Resource Ventures Incorporated recognizes that certain of the data and information requested and required by Resource Ventures Incorporated may be considered confidential and proprietary to the Company, Resource Ventures Incorporated hereby undertakes to guarantee and promise the company that any use, release, or publication of data and information supplied by the Company will be under the terms and conditions set forth as follows: Resource Ventures Incorporated agrees to abide by the following terms:

1. CONFIDENTIAL DATA AND information received from the Company will be placed in a secure file at Resource Ventures Incorporated office in Charlottetown, Prince Edward Island and no copies, transcriptions, reproductions of any form will be made of said data and information in whole or in part.

2. CONFIDENTIAL DATA AND information supplied will be seen only by the study consultants, Mr. Malcolm Lodge, Mr. Stewart Bennie, and Mr. Carl Brothers whose signatures are affixed hereon.

3. THOSE DATA AND information designated by the Company to be of a confidential nature will be processed by Resource Ventures Incorporated using such methods as:

(a) normalization of size, weight, and ratings of machines;

(b) combination of components to generic subassemblies;

(c) generic description of performance, operation, and maintenance characteristics and requirements.

4. ALL RESULTS OF analysis and conclusion and all illustrations, graphs, tables, and descriptions in which data specified as confidential by the Company is represented will be provided to the Company for approval prior to any release or publication.

5. ALL COPIES OF the final report will be clearly marked confidential and copies will be supplied only to participating manufacturers and the Department of Energy, Mines, and Resources, Canada.

6. THE COMPLETED QUESTIONNAIRE supplied by the Company will be returned to the Company following completion of the study.

7. FOLLOWING COMPLETION OF the study, all data and information stored or contained in computer will be destroyed or erased.

IN WITNESS THEREOF, the undersigned undertake to abide by the terms of this Certificate of Non-Disclosure.

Malcolm A. Lodge for RESOURCE VENTURES INC.	27/3/86 Date	Witness
Stewart H. Bennie for RESOURCE VENTURES INC.	Mar 27/86 Date	Witness
Carl Brothers for RESOURCE VENTURES INC.	Mar 27/86 Date	Witness